



Mobility: Vehicle Dynamics, Control and Autonomous Behavior

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IS MOBILITY IMPORTANT?

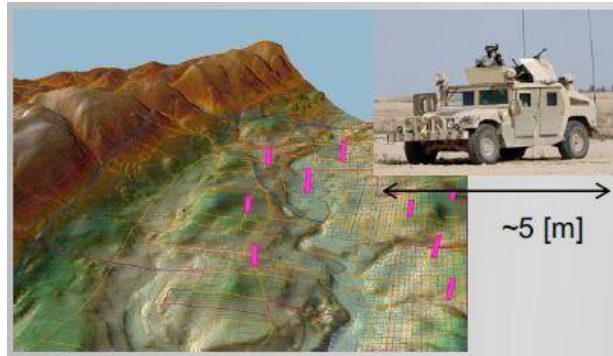




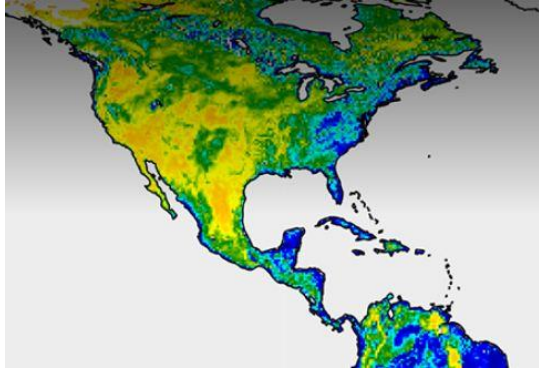
NATO AVT-248 OBJECTIVE: NEXT-GEN NATO REFERENCE MOBILITY MODEL



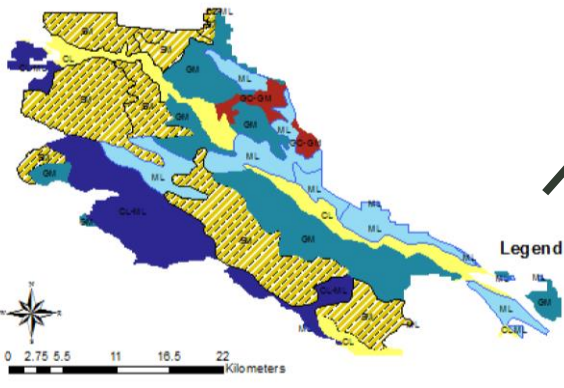
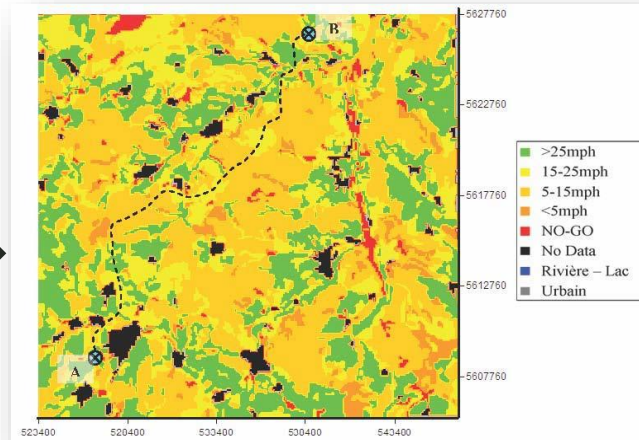
Terrain Elevation Map



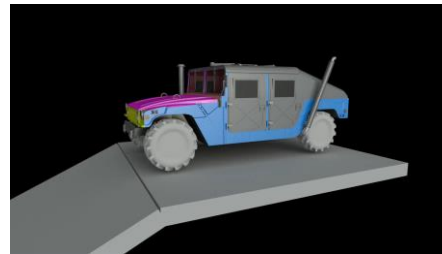
Soil Moisture Map



Mobility Go/NoGo Map



Soil Type



Physics-Based M&S

Qualitative

NRMM

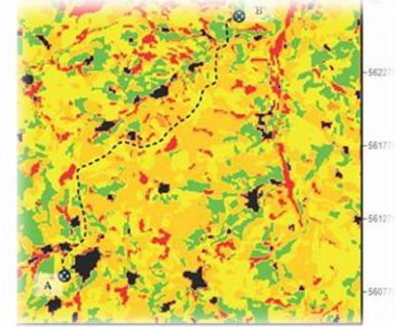
NG-NRMM

1970

2020



ADDRESSING COMPUTATIONAL CHALLENGE THROUGH FAST NUMERICAL ALGORITHMS



□ Army Relevance

- Empirical methods for mobility map generation are expensive
- High-fidelity simulations alleviate the cost, critical for next-generation UGVs
- Challenging multi-physics and multi-scale problem

□ Technical Challenge

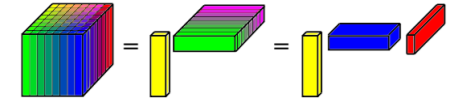
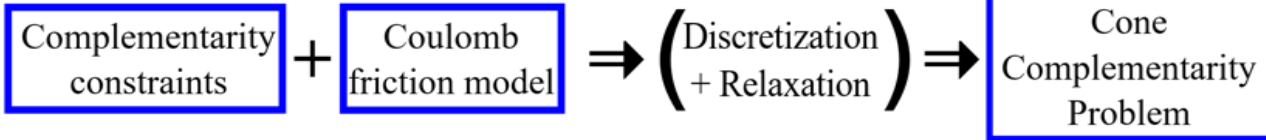
- **DEM-Complementarity** approach is numerically stable compared to widely-used **DEM-Penalty**
- Current HPC implementations of DEM-C centered around shared-memory & GPU architectures; problem-sizes limited by memory
- Vehicle-soil interaction simulations require efficient, distributed memory implementations

□ Project Goal

- Make large-scale, high-fidelity terramechanics simulations accessible through a combination of **novel fast algorithms** and **high performance computing**

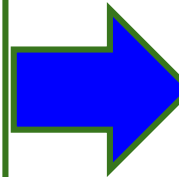


ADDRESSING COMPUTATIONAL CHALLENGE THROUGH FAST NUMERICAL ALGORITHMS



Basic Research Questions

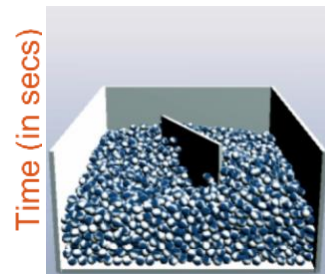
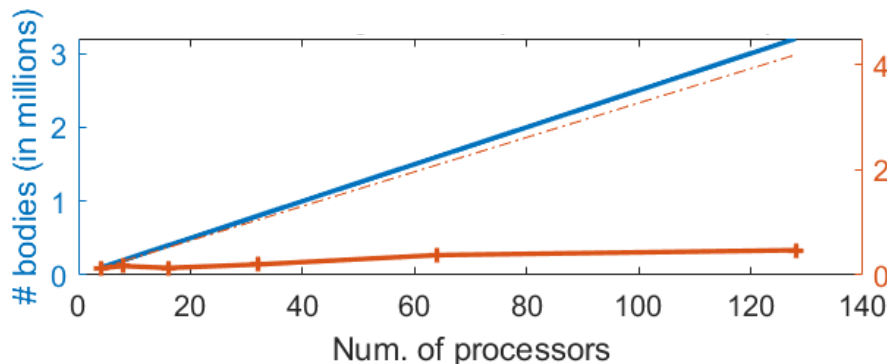
- Can the Newton matrices be hierarchically compressed?
- How does this affect scaling of costs?
- How to account for low-rank updates as the optimization proceeds?



Tensor Train Decomposition

- ★ **Sublinear** storage and matrix factorization costs
- ★ **$O(N \log N)$** matrix apply and solve
- ★ **Sublinear** factorization “low rank” updates

Parallel Implementation



Project Deliverables

- Parallel DEM-C implementation of first- & second-order methods
- Distributed TT direct solvers
- NATO CDT V&V

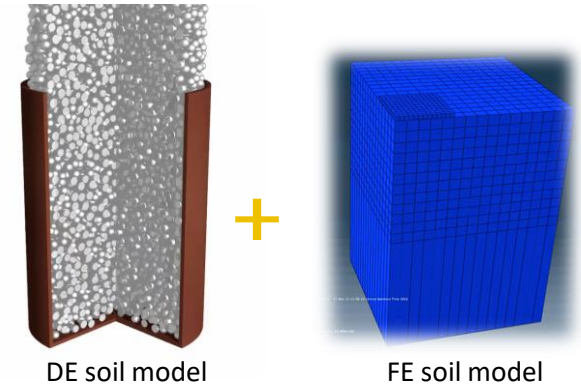


ADDRESSING COMPUTATIONAL CHALLENGES THROUGH MULTI-SCALE TERRAIN MODELING



□ Army Relevance

- Mobility prediction is important to achieve challenging missions and to ensure survivability of soldiers
- Needs **high-fidelity physics-based** off-road mobility models for NextGen NATO Reference Mobility Model (NG-NRMM)

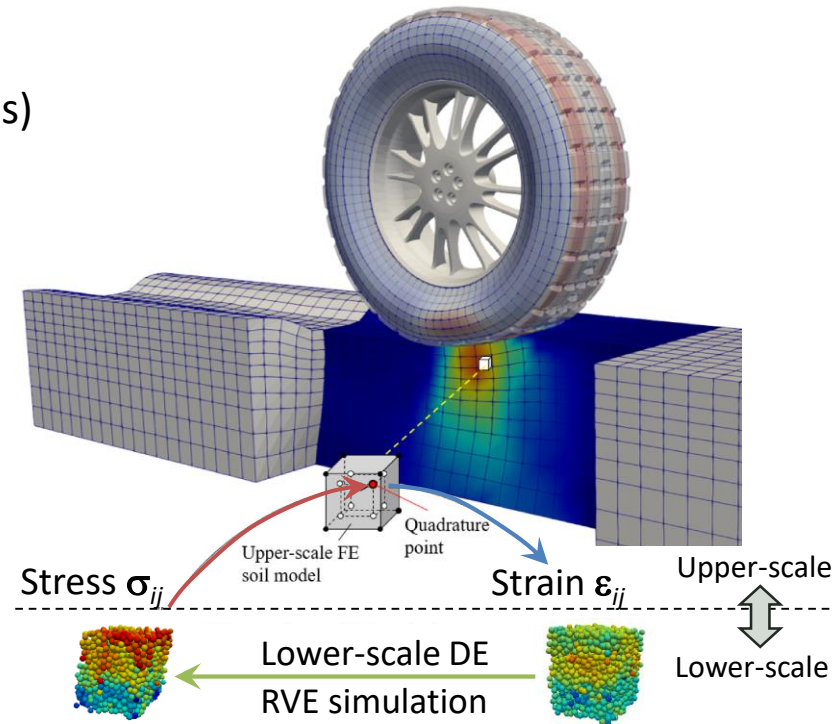


□ Technical Challenges

- Very high computational cost (DE models)
- Modeling large deformation soil behavior (FE models)
- Full-scale verification and validation (V&V)

□ Project Goals

- Develop a novel **hierarchical FE-DE multi-scale** tire-soil interaction model
- Develop a scalable parallel computing algorithm for multi-scale off-road mobility solver



PI: Hiroyuki Sugiyama, Iowa



ADDRESSING COMPUTATIONAL CHALLENGES THROUGH MULTI-SCALE TERRAIN MODELING



☐ Multiscale Terrain Model Validation



Triaxial soil compression test

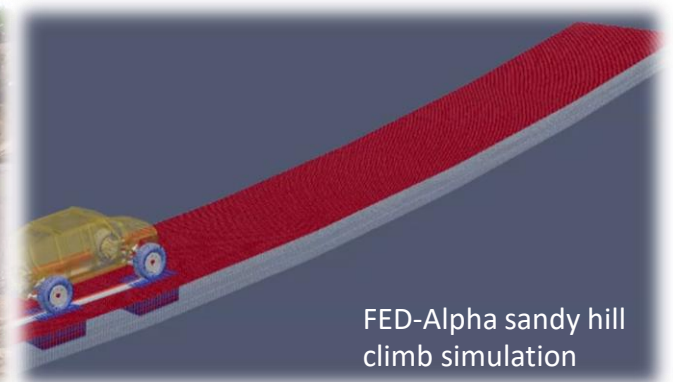


Single wheel soil bin mobility test at Caterpillar

Off-road vehicle mobility test & simulation



NextGen NRMM Cooperative Demonstration of Technology (CDT) test



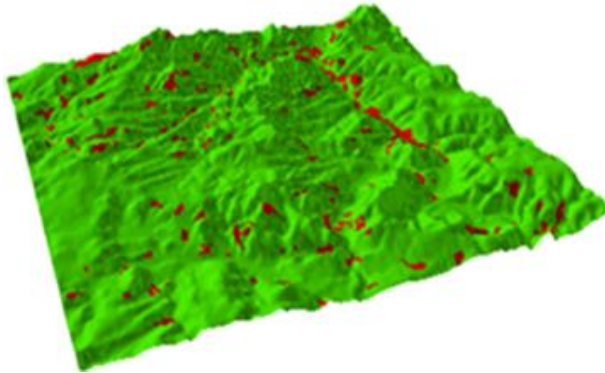
FED-Alpha sandy hill climb simulation



REMOTE TERRAIN STRENGTH CHARACTERIZATION THROUGH THERMAL AND HYPERSPECTRAL SENSING



Army Relevance: Go/NoGo maps are critical for mission planning



State of the art: Terrain strength characterization



Measuring cone index in the remodeling cylinder before and after hammer blows.



Bevameter

NG-NRMM Data Requirements

Scenario data: Snow depth, freeze-thaw depth, seasonal visibility, obstacles, etc.

Terrain data: USCS soil type classification, **soil strength**, slope, land use, surface condition, roughness, etc.

Vehicle input: Drivetrain, wheelbase and axle positions, general dimensions, etc.

Limitations:

- Relies heavily on in-situ soil measurements
- In situ terrain data collection can put the soldiers in harms way

Project Goal:

Develop **remote** terrain strength characterization to support safe combat operation in unknown territories

PI: Thomas Oommen, MTU



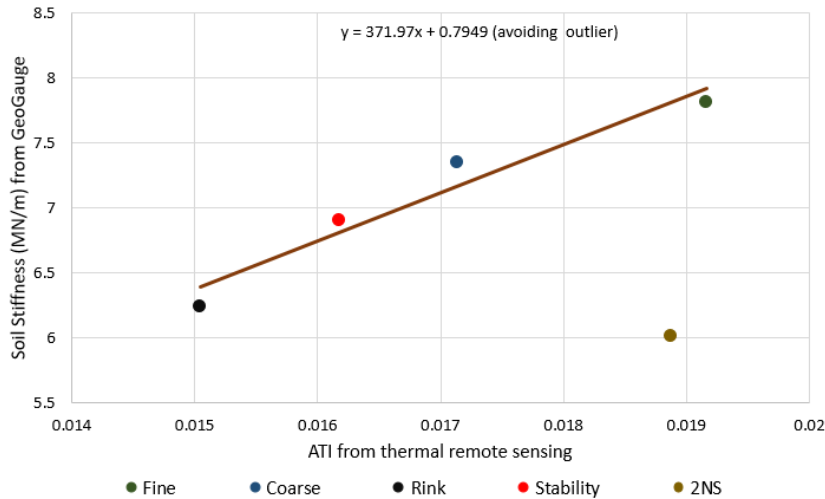
REMOTE TERRAIN STRENGTH CHARACTERIZATION THROUGH THERMAL AND HYPERSENSPECTRAL SENSING



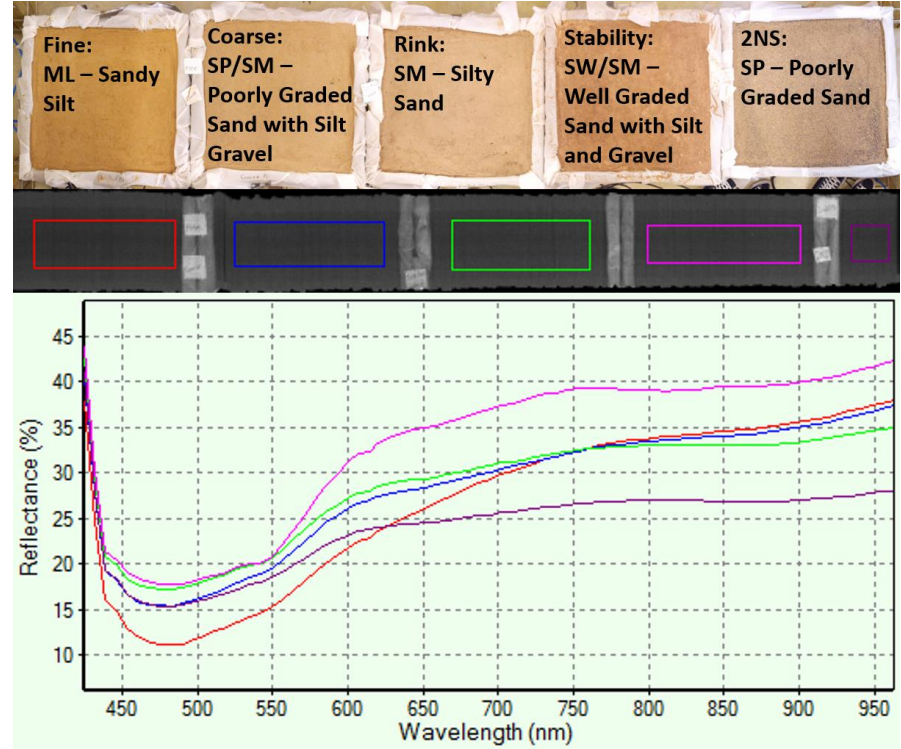
Basic Research: Understanding the relation between electromagnetic radiation and soil types with varying properties.

Results:

Soil Stiffness vs Apparent Thermal Inertia (ATI)



- Apparent Thermal Inertia (ATI) is a measure of material resistance to change in temperature
- Shows a linear trend between soil stiffness and ATI



- Hyperspectral plot for different soil types
- Shows a unique spectral signature demonstrating the potential of hyperspectral sensing for soil type classification



ARE WE TAKING AUTONOMY FOR GRANTED?



JACK STEWART TRANSPORTATION 03.30.18 10:34 PM

TESLA'S AUTOPILOT WAS INVOLVED IN ANOTHER DEADLY CAR CRASH



- Lane detection error
- Median detection error
- Failed to brake
- Accelerated instead
- Autonomy level 3 vs. 4

ALEX DAVIES TRANSPORTATION 06.22.18 01:12 PM

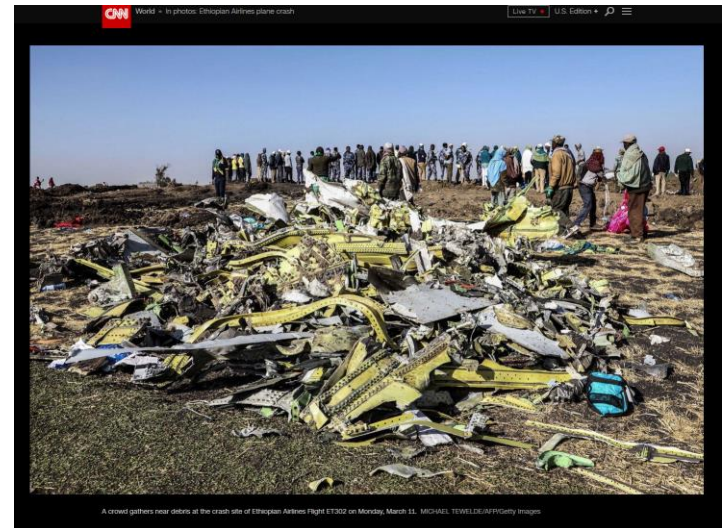
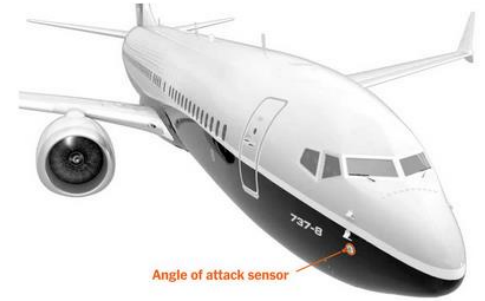
THE UNAVOIDABLE FOLLY OF MAKING HUMANS TRAIN SELF-DRIVING CARS



- Only 1 LIDAR on roof
- 3 m blind spot
- Pedestrian classification and action delay
- Driver watching TV on phone
- Didn't brake

The Dangerous Flaws in Boeing's Automated System

Here's why a system designed to stabilize the 737 Max may have caused two deadly crashes in five months.



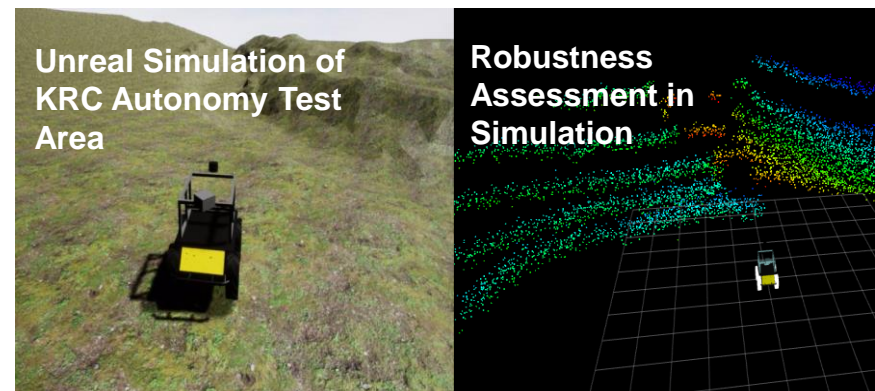
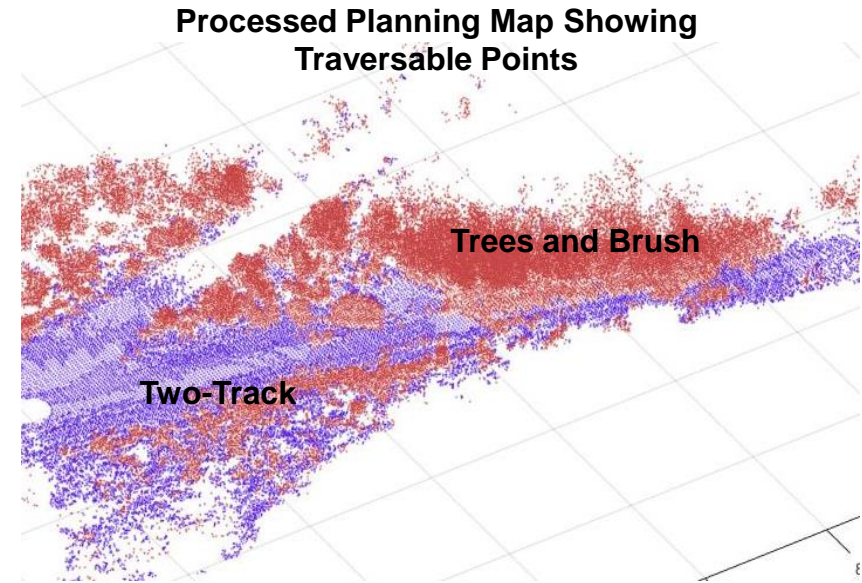
- Faulty sensor
- No redundancy
- Death Toll: 346



EXTENDING PATH PLANNERS TO OFF-ROAD ENVIRONMENTS



- **Army Relevance: Off-road** autonomous path planning in 3D through:
 - Closely spaced obstacles (trees)
 - Areas with overhead obstructions
 - Challenging terrain (large rocks / boulders)
 - Varied terrain type (snow, sand, mud)
- **Technical Challenge:**
 - Develop 3D cost-map path planners that address Army needs
 - Do not require excessive point-cloud data
 - Robustness
- **Basic Research Opportunities:**
 - Can we augment existing planners to include **terrain assessment** using camera, machine learning, and feedback?
 - What is the **minimum sensor complement & fidelity** required for robust path planning?



PI: Jeremy Bos, MTU



EXTENDING PATH PLANNERS TO OFF-ROAD ENVIRONMENTS



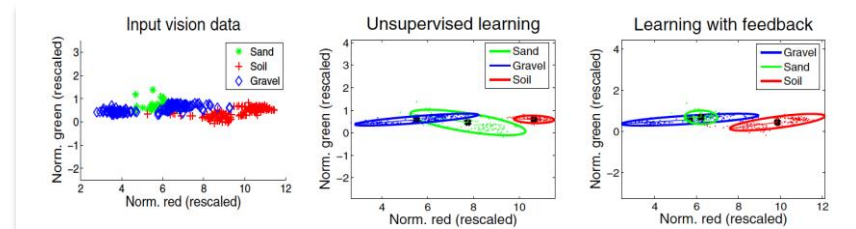
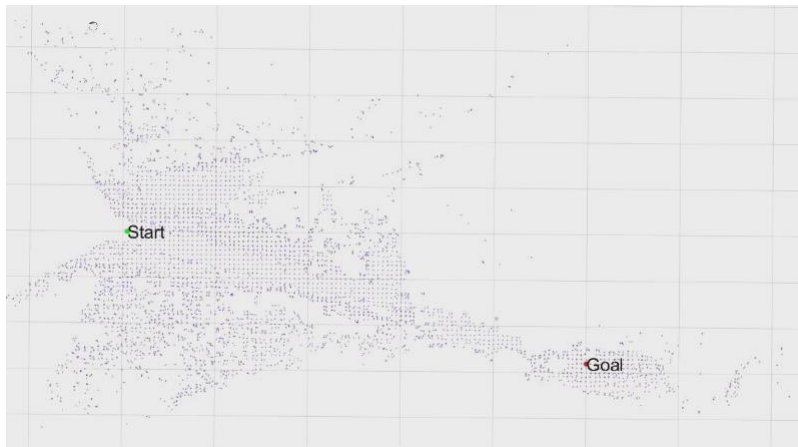
Point Cloud Based Path Planning

+

Visual Terrain Assessment via Machine Learning

+

Feedback and Predication via Onboard Sensors



Angelova, A., et al. Automation, 2007 IEEE International Conference on. 2007. IEEE.

Outcome: Robust point-cloud based path planning and terrain assessment using minimum sensor complement





ENABLING DECISION MAKING IN AUTONOMOUS VEHICLE DESIGN



PI: Vijit Pandey, Oakland

Army Relevance: The Army has to compare different vehicle designs, autonomy levels, sensor suites, etc. for acquisition and operational decisions.

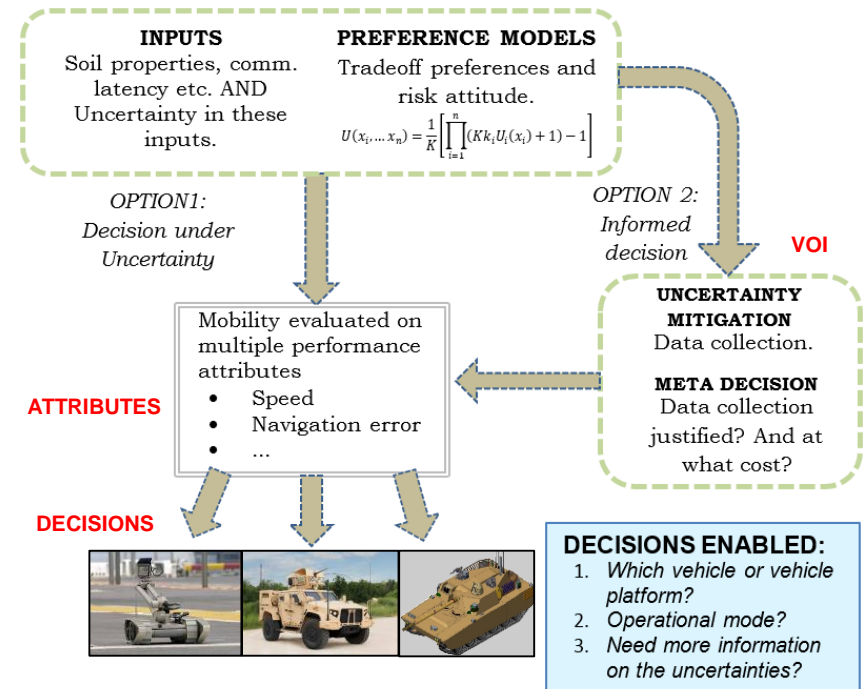
- A formal approach can reduce ambiguity, improve repeatability, and increase optimality of these decisions.

Technical Challenge:

Disparate models map inputs to attributes. No unified framework exists for multiple attributes.

Basic Research Questions:

- What **utility theoretic models** are suitable for this application?
- How to calculate the **value of information** on uncertainties over multiple attributes?



Vehicle	Time (s)	Error (m)	Torque/Wt. (Nm/Kg)	Cost (\$1000)	U (t, e, q, c)
Generic 4x4	142.9	99.79	0.1689	80	0.7696
Standard APD	187.8	86.82	0.6106	120	0.6996
Modified APD	167.9	85.48	1.0610	150	0.6978



AUGMENTING AI WITH DOMAIN KNOWLEDGE

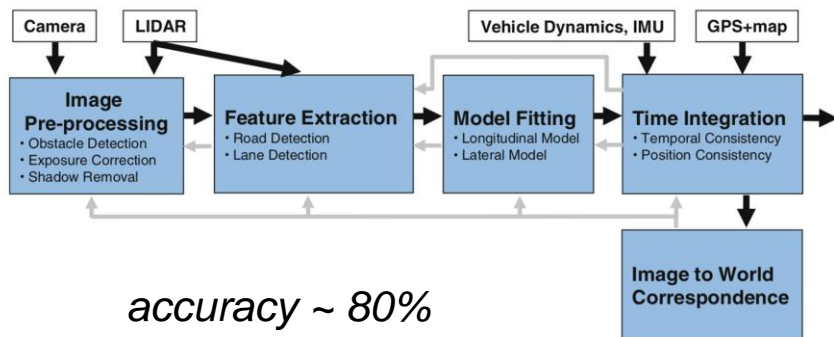


PI: Hwei Peng, Michigan

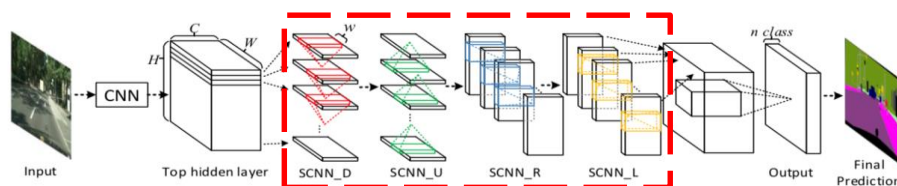
❑ **Army Relevance:** Improve the accuracy and reliability of AI for mission-critical applications

❑ **Lane detection example**

Traditional feature-based approach



DNN-based approach



❑ **Proposed approach: combining domain knowledge and DNN** *accuracy ~ 90%*

